Diploma Programme
Programme du diplôme
Programa del Diploma

# Chemistry
# Higher level
# Paper 2

Thursday 14 May 2015 (afternoon)

Candidate session number

| | | | | | | | | | |
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| | | | | | | | | | |

2 hours 15 minutes

**Instructions to candidates**

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.

2215–6114

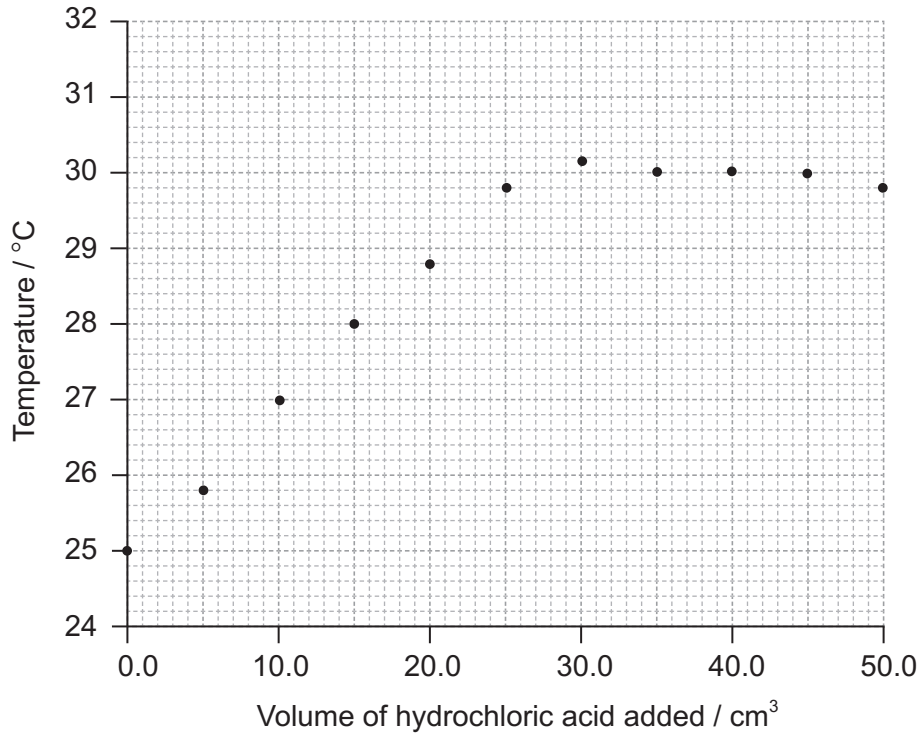
28 pages

## Section A

Answer **all** questions. Write your answers in the boxes provided.

**1.** A student carried out an experiment to determine the concentration of a hydrochloric acid solution and the enthalpy change of the reaction between aqueous sodium hydroxide and this acid by thermometric titration.

She added 5.0 $cm^3$ portions of hydrochloric acid to 25.0 $cm^3$ of 1.00 $mol\,dm^{-3}$ sodium hydroxide solution in a glass beaker until the total volume of acid added was 50.0 $cm^3$, measuring the temperature of the mixture each time. Her results are plotted in the graph below.




The initial temperature of both solutions was the same.

(a) (i) By drawing appropriate lines, determine the volume of hydrochloric acid required to completely neutralize the 25.0 $cm^3$ of sodium hydroxide solution. [2]

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**(This question continues on the following page)**

**(Question 1 continued)**

(ii) Determine the concentration of the hydrochloric acid, including units. [2]

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(b) (i) Determine the change in temperature, $\Delta T$. [1]

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(ii) Calculate the enthalpy change, in $kJ\,mol^{-1}$, for the reaction of hydrochloric acid and sodium hydroxide solution. [3]

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(iii) The accepted theoretical value from the literature of this enthalpy change is $-58\,kJ\,mol^{-1}$. Calculate the percentage error correct to **two** significant figures. [1]

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**(This question continues on the following page)**

**(Question 1 continued)**

(iv) Suggest the major source of error in the experimental procedure **and** an improvement that could be made to reduce it. [2]

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**2.** (a) Define the term *rate of reaction*. [1]

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(b) Explain why increasing the particle size of a solid reactant decreases the rate of reaction. [2]

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(c) Nitrogen(II) oxide reacts with hydrogen according to the equation below.

$$2NO(g) + 2H_2(g) \rightarrow N_2(g) + 2H_2O(g)$$

A suggested mechanism for this reaction is:

| | | |
|---|---|---|
| Step 1: | $NO + H_2 \rightleftharpoons X$ | fast |
| Step 2: | $X + NO \rightarrow Y + H_2O$ | slow |
| Step 3: | $Y + H_2 \rightarrow N_2 + H_2O$ | fast |

(i) Identify the rate-determining step. [1]

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(ii) A student hypothesized that the order of reaction with respect to $H_2$ is 2. Evaluate this hypothesis. [2]

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**3.** Carbon monoxide reacts with hydrogen to produce methanol.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$$

| Substance | $\Delta H_f^\ominus$ / kJ mol$^{-1}$ | $\Delta G_f^\ominus$ / kJ mol$^{-1}$ | $S^\ominus$ / J mol$^{-1}$ K$^{-1}$ |
|---|---|---|---|
| CO (g) | – 110.5 | – 137.2 | + 197.6 |
| $CH_3OH$ (l) | – 239.0 | – 166.0 | + 126.8 |

(a) Calculate the standard enthalpy change, $\Delta H^\ominus$, in kJ mol$^{-1}$, for the reaction. [1]

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(b) Calculate the standard free energy change, $\Delta G^\ominus$, in kJ mol$^{-1}$, for the reaction ($\Delta G_f^\ominus(H_2) = 0$ kJ mol$^{-1}$). [1]

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(c) Using the values obtained in parts (a) and (b), calculate the standard entropy change, $\Delta S^\ominus$, in J mol$^{-1}$ K$^{-1}$, for the reaction at 298 K. [1]

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(d) Determine the absolute entropy, $S^\ominus$, in J mol$^{-1}$ K$^{-1}$, for $H_2$ (g) at 298 K. [2]

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**4.** A buffer solution with a pH of 3.87 contains 7.41 g $dm^{-3}$ of propanoic acid, $CH_3CH_2COOH$, together with an unknown quantity of sodium propanoate, $CH_3CH_2COONa$.

(a) Define the term *buffer solution*. [2]

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(b) Explain, using appropriate equations, how this solution acts as a buffer solution. [2]

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(c) Calculate the concentration, in mol $dm^{-3}$, of sodium propanoate in this buffer solution. The p$K_a$ of propanoic acid is 4.87 at 298 K. [4]

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**5.** (a) State **two** features of a homologous series. [2]

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(b) Ethane, a member of the homologous series of alkanes, can react with bromine. Explain the free-radical mechanism of this reaction, including any necessary reaction conditions. [4]

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**6.** Electrolysis is an important industrial process used to obtain very reactive elements from their common ores.

(a) Molten magnesium chloride can be electrolysed using inert graphite electrodes at 800 °C.

Deduce the half-equations, including state symbols, for the reactions occurring at each electrode. (The melting points of $MgCl_2$ and Mg are 714 °C and 649 °C respectively.) [3]

Positive electrode (anode):

. . . . . .

Negative electrode (cathode):

. . . . . .

(b) Aluminium can also be obtained by electrolysis. Suggest **one** reason why aluminium is often used instead of iron by engineers. [1]

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## Section B

Answer **two** questions. Write your answers in the boxes provided.

**7.** When nitrogen gas and hydrogen gas are allowed to react in a closed container the following equilibrium is established.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92.6\,kJ$$

(a) (i) Outline **two** characteristics of a reversible reaction in a state of dynamic equilibrium. [2]

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(ii) Predict, with a reason, how each of the following changes affects the position of equilibrium. [2]

The volume of the container is increased.

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Ammonia is removed from the equilibrium mixture.

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(iii) Define the term *activation energy*, $E_a$. [1]

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**(This question continues on the following page)**

**(Question 7 continued)**

(b) Ammonia is manufactured by the Haber process in which iron is used as a catalyst. Explain the effect of a catalyst on the rate of reaction. [2]

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(c) Typical conditions used in the Haber process are 500 °C and 200 atm, resulting in approximately 15 % yield of ammonia.

(i) Explain why a temperature lower than 500 °C is **not** used. [2]

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(ii) Outline why a pressure higher than 200 atm is **not** often used. [1]

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**(This question continues on the following page)**

**(Question 7 continued)**

(d) (i) Deduce the equilibrium constant expression, $K_c$, for the reaction on page 10. [1]

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(ii) When 1.00 mol of nitrogen and 3.00 mol of hydrogen were allowed to reach equilibrium in a 1.00 $dm^3$ container at a temperature of 500 °C and a pressure of 1000 atm, the equilibrium mixture contained 1.46 mol of ammonia.

Calculate the value of $K_c$ at 500 °C. [2]

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(e) (i) Define the term *base* according to the Lewis theory. [1]

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(ii) Define the term *weak base* according to the Brønsted–Lowry theory. [1]

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**(This question continues on the following page)**

**(Question 7 continued)**

(iii) Deduce the formulas of conjugate acid-base pairs in the reaction below.

$$CH_3NH_2(aq) + H_2O(l) \rightleftharpoons CH_3NH_3^+(aq) + OH^-(aq)$$ [2]

| Acid | Conjugate base |
|---|---|
| . . . . . | . . . . . |
| . . . . . | . . . . . |

(f) Determine the pH of a $0.100\,mol\,dm^{-3}$ solution of ammonia, $NH_3(aq)$, using tables 2 and 15 of the data booklet. [4]

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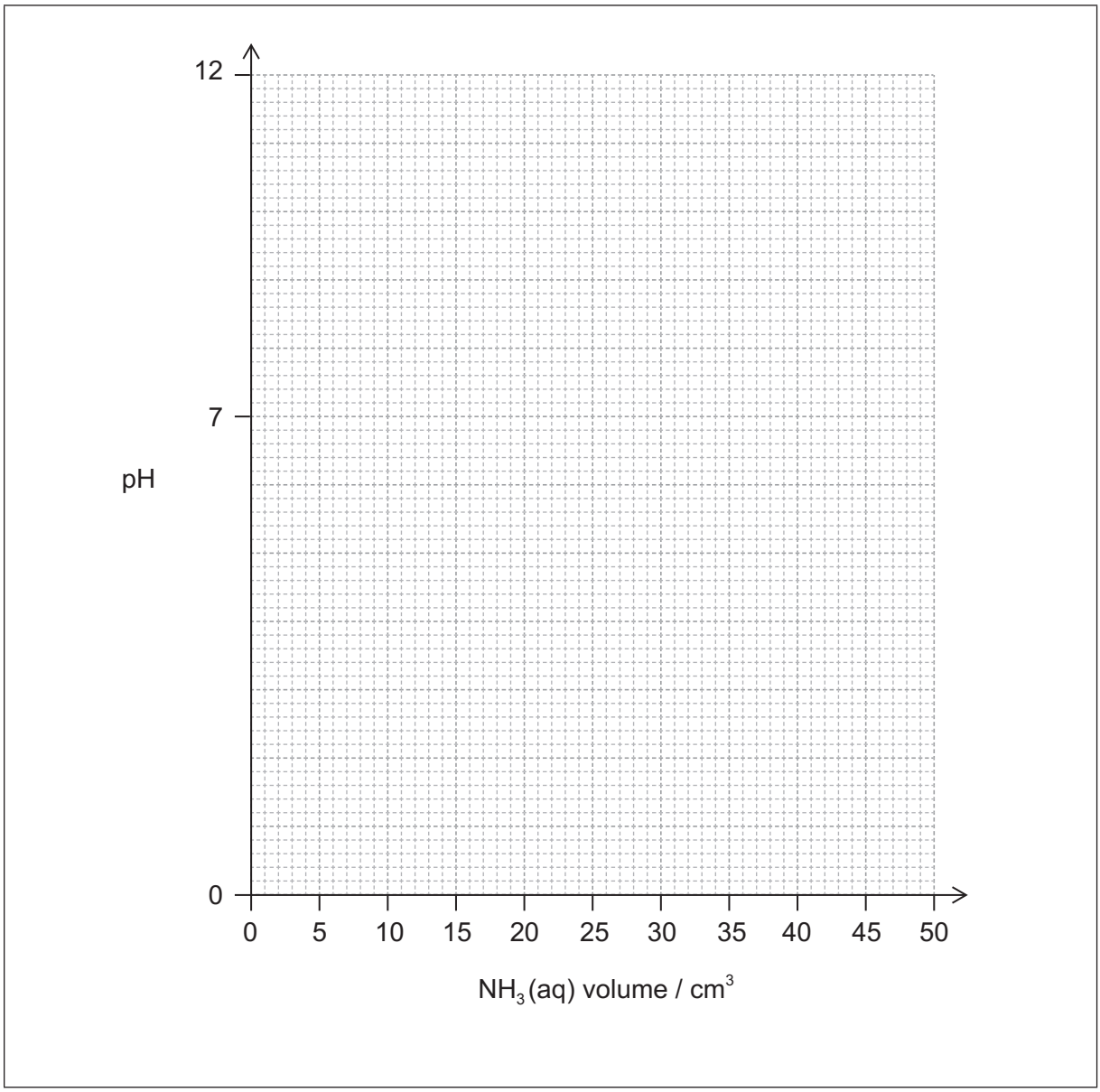
**(This question continues on the following page)**

**(Question 7 continued)**

(g) (i) Sketch the pH titration curve obtained when 50.0 $cm^3$ of 0.100 mol $dm^{-3}$ $NH_3$(aq) is added to 25.0 $cm^3$ of 0.100 mol $dm^{-3}$ HCl(aq). [3]




(ii) Identify an indicator from table 16 of the data booklet that could be used for this titration. [1]

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**8.** Chromium is a transition metal with many uses.

(a) (i) Draw an orbital diagram (using the arrow-in-box notation) showing the electrons in the 4s and 3d sub-levels in chromium metal. [1]

(ii) Outline the nature of the metallic bonding present in chromium. [1]

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(iii) Explain why chromium metal is malleable. [1]

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(b) (i) State the name of $Cr_2O_3$. [1]

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(ii) Describe the ionic bonding present in $Cr_2O_3$ and how the ions are formed. [2]

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**(This question continues on the following page)**

**(Question 8 continued)**

(iii) Suggest why solid $Cr_2O_3$ does **not** conduct electricity. [1]

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(c) Chromium forms the complex ion $[Cr(NH_3)_4Cl_2]^+$.

(i) Deduce the oxidation number of chromium in this complex. [1]

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(ii) Describe the nature of the ligand-chromium ion bonds in terms of acid-base theory. [2]

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(iii) Explain why $[Cr(NH_3)_4Cl_2]^+$ is coloured. [4]

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**(This question continues on the following page)**

**(Question 8 continued)**

(iv) Draw the structures of **two** possible isomers of this complex ion. [2]

(d) (i) The dichromate ion, $Cr_2O_7^{2-}(aq)$, and the iodide ion, $I^-(aq)$, react together in the presence of an acid to form $Cr^{3+}(aq)$ and $IO_3^-(aq)$ ions. Deduce the half-equation for the reaction of $I^-$ to $IO_3^-$ and the overall equation for this reaction. [2]

Half-equation:

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. . . . . .

Overall equation:

. . . . . .
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(ii) Explain in terms of oxidation numbers whether iodine is oxidized or reduced in part (d) (i). [1]

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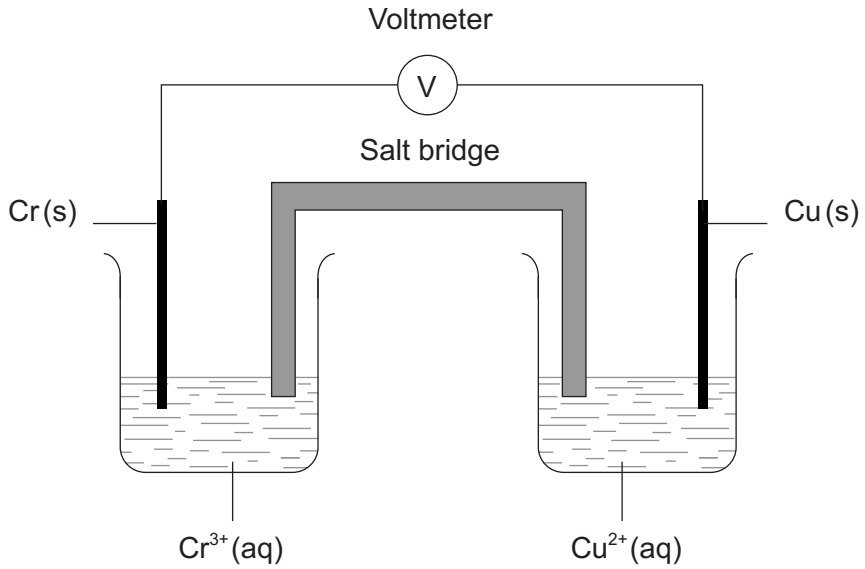
**(This question continues on the following page)**

**(Question 8 continued)**

(e) A voltaic cell is constructed as follows. One half-cell contains a chromium electrode immersed in a solution containing $Cr^{3+}(aq)$ ions. The other half-cell contains a copper electrode immersed in a solution containing $Cu^{2+}(aq)$ ions. The two electrodes are connected to a voltmeter and the two solutions by a salt bridge.




(i) Define the term *standard electrode potential*. [1]

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(ii) Calculate the cell potential, in V, under standard conditions, for this voltaic cell, using table 14 of the data booklet and $E^{\ominus}_{Cr^{3+}/Cr} = -0.74\,V$. [1]

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**(This question continues on the following page)**

**(Question 8 continued)**

(iii) Predict the balanced equation for the spontaneous reaction which will produce a current in this voltaic cell. [1]

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(iv) Identify the negative and the positive electrodes in this cell. [1]

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(v) Predict the direction of movement of electrons in the external circuit. [1]

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(vi) State the directions in which the negative ions (anions) and the positive ions (cations) flow in the salt bridge. [1]

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**9.** (a) Consider the structure and bonding in $MgCl_2$ and $PCl_3$.

(i) State and explain the electrical conductivities of these two chloride compounds in their liquid state. [3]

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(ii) Suggest, giving your reasons, the approximate pH values of the solutions formed by adding each chloride compound separately to distilled water. [4]

$MgCl_2$:

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$PCl_3$:

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(b) (i) Identify the acid-base character of the oxides of each of the elements from sodium to chlorine in period 3. [2]

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**(This question continues on the following page)**

**(Question 9 continued)**

(ii) State the equations for the separate reactions of sodium oxide and phosphorus(V) oxide with water. [2]

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(c) Consider the molecules $PBr_3$ and $SF_4$.

(i) Deduce the Lewis (electron dot) structure of both molecules. [2]

(ii) Predict the shapes of the two molecules, giving the Br–P–Br bond angle in $PBr_3$ and the F–S–F bond angles in $SF_4$. [4]

| **$PBr_3$** | **$SF_4$** |
|---|---|
| Shape:<br>. . . . . .<br>. . . . . .<br>Bond angle:<br>. . . . . .<br>. . . . . . | Shape:<br>. . . . . .<br>. . . . . .<br>Bond angles:<br>. . . . . .<br>. . . . . . |

**(This question continues on the following page)**

**(Question 9 continued)**

(iii) Explain why both $PBr_3$ and $SF_4$ are polar. [2]

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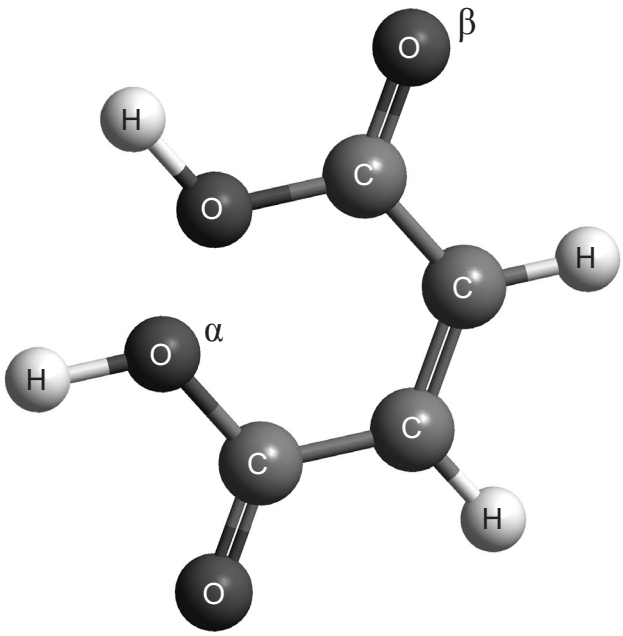
(d) The structure of *cis*-but-2-ene-1,4-dioic acid is shown below.




(i) Describe the covalent bond between carbon and hydrogen in the molecule above and how it is formed. [2]

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**(This question continues on the following page)**

**(Question 9 continued)**

(ii) Deduce the hybridization of the oxygen atoms labelled α and β. [1]

α:

. . . . . .

β:

. . . . . .

(iii) Describe sigma (σ) and pi (π) bonds between atoms. [2]

σ bond:

. . . . . .
. . . . . .

π bond:

. . . . . .
. . . . . .

(iv) Identify the number of sigma (σ) and pi (π) bonds present in a molecule of *cis*-but-2-ene-1,4-dioic acid. [1]

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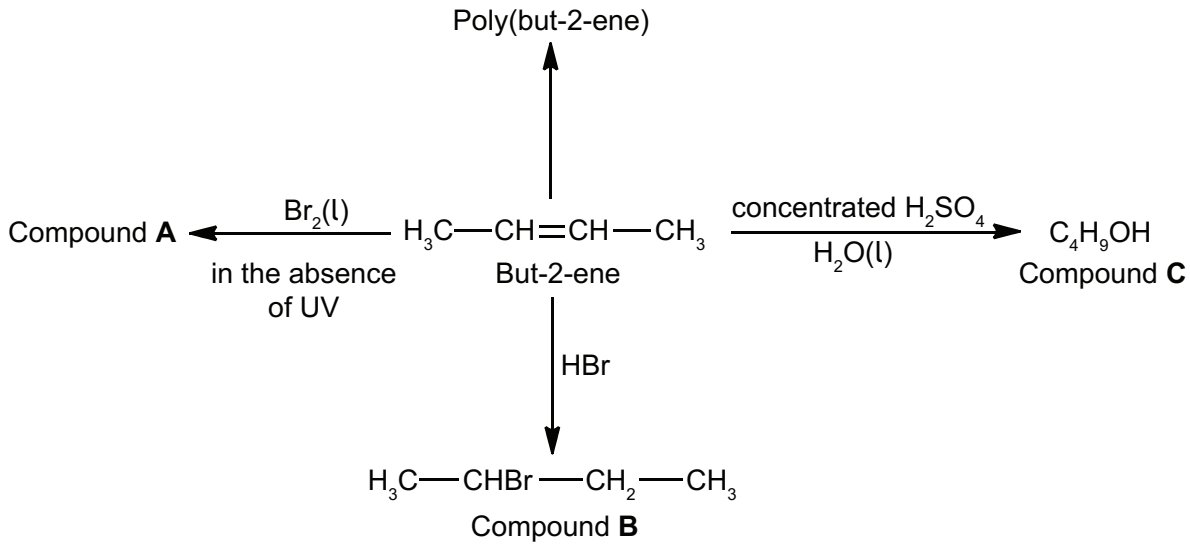
**10.** Some reactions of but-2-ene are given below.




(a) (i) Deduce the full structural formula of compound **A**. [1]

(ii) Apply IUPAC rules to name compound **A**. [1]

. . . . . .

(iii) Describe the colour change observed when excess but-2-ene reacts with bromine to form compound **A**. [1]

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**(This question continues on the following page)**

**(Question 10 continued)**

(b) (i) Outline **two** reasons why the polymerization of alkenes is of economic importance. [2]

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(ii) Identify the structure of the repeating unit of poly(but-2-ene). [1]

(c) (i) Compound **C**, $C_4H_9OH$, can also be formed by reacting compound **B**, $CH_3CHBrCH_2CH_3$, with aqueous potassium hydroxide. This reaction proceeds by both $S_N1$ and $S_N2$ mechanisms. Explain the $S_N2$ mechanism, using curly arrows to represent the movement of electron pairs. [4]

**(This question continues on the following page)**

**(Question 10 continued)**

(ii) Explain why the hydroxide ion is a better nucleophile than water. [2]

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(d) (i) Compound **B**, $CH_3CHBrCH_2CH_3$, also reacts with potassium cyanide. Apply IUPAC rules to name the organic product formed. [1]

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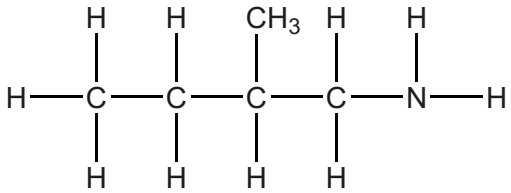
(ii) The organic product of the reaction in part (d) (i) can be reduced to:



State the **two** reagents required. [1]

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(iii) Deduce the full structural formula of the organic product formed when the compound in part (d) (ii) reacts with ethanoic acid in the presence of an acid catalyst. [1]

**(This question continues on the following page)**

**(Question 10 continued)**

(e) Compound **C**, $C_4H_9OH$, can be oxidized by acidified potassium dichromate(VI) to form compound **F**.

(i) State the name of the functional group present in compound **F**. [1]

. . . . . .

(ii) Deduce the structural formula of an alcohol which is a structural isomer of compound **C** and **cannot** be oxidized by acidified potassium dichromate(VI). [1]

(f) Explain why but-2-ene is more volatile than compound **C**. [2]

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(g) Deduce the equation for the complete combustion of compound **C**. [1]

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**(This question continues on the following page)**

**(Question 10 continued)**

(h) But-2-ene can exist as two geometrical isomers. Geometrical isomerism is a form of stereoisomerism.

(i) Define the term *stereoisomers*. [1]

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(ii) State the conditions needed for a compound to show geometrical isomerism. [2]

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(iii) Draw the structures of the two geometrical isomers of but-2-ene, clearly identifying each as *cis* or *trans*. [2]